Soil C, N, and P from Poultry Manure on Grazed and Ungrazed Bermudagrass in the Southeastern USA

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Abstract

The impact of animal manure application to grasslands is of importance to the understanding of agronomic and animal productivity, soil quality, greenhouse gas emissions, and environmental quality. Pastures have the potential to serve as a significant sink for carbon (C) sequestered in soil organic matter. Efficient utilization of nitrogen (N) is of concern agronomically and environmentally. Plant production can be limited by low levels of available phosphorus (P) due to high P fixation capacity in soils of the southeastern USA. On the other hand, there is increasing concern about the excessive application of P to soil, especially when manure application rate is based upon N content.

We evaluated the changes in soil C, N, and P during the first five years of bermudagrass [*Cynodon dactylon* (L.) Pers.] management varying in fertilization [(1) inorganic, (2) crimson clover (*Trifolium incarnatum* L.) cover crop plus inorganic, and (3) chicken (*Gallus gallus*) broiler litter] and harvest strategies [(1) unharvested, (2) low and (3) high cattle (*Bos taurus*) grazing pressure, and (4) haying).

Fertilization strategy had the greatest impact on total and extractable soil P, while soil organic C and total soil N were minimally affected. At a depth of 0 to 6 cm, extractable soil P increased at a rate of 0.8 mg $\cdot$ kg^{-1} $\cdot$ yr^{-1} (4 % of total P added) with inorganic only, 2.4 mg $\cdot$ kg^{-1} $\cdot$ yr^{-1} (9 % of total P added) with clover + inorganic, and 8.7 mg $\cdot$ kg^{-1} $\cdot$ yr^{-1} (6 % of total P added) with broiler litter fertilization. At the end of five years of broiler litter application to grazed land, extractable soil P was 135, 50, 22, and 4 mg $\cdot$ kg^{-1} higher than with inorganic fertilization at depths of 0 to 3, 3 to 6, 6 to 12, and 12 to 20 cm, respectively, primarily because of greater P application with broiler litter.

Harvest strategy had large impacts on all soil elements. Soil organic C sequestration during the first five years of management was similar between low and high cattle grazing pressures (140 g $\cdot$ m^{-2} $\cdot$ yr^{-1}), but much less in unharvested (65 g $\cdot$ m^{-2} $\cdot$ yr^{-1}) and hayed (29 g $\cdot$ m^{-2} $\cdot$ yr^{-1}) management. Most of the net change in soil organic C and total soil N occurred in the 0- to 2-cm depth. With cattle grazing of forage, fertilizer applications contributed to forage and animal production and 67-75% of the total N applied was subsequently stored as total soil N.

Broiler litter fertilization was effective at increasing extractable soil P to an agronomically acceptable level (50 to 60 mg $\cdot$ kg^{-1} $\cdot$ 15 cm^{-1}) during the first five years, but continued application could lead to excessive P accumulation that could threaten water quality from surface runoff unless appreciable soil fixation or removal of forage biomass were to occur.

1. Introduction

Soils in the Appalachian Piedmont region of the USA have been degraded during decades of intensive tillage, which has caused serious erosion and loss of organic matter. Conversion of cropland to forages has the potential to restore soil organic matter and build fertility. Cattle consume forage and deposit manure, which alters the timing and spatial distribution of nutrient cycling in pastures.

Nitrogen is the most limiting nutrient required by plants. Forage grasses respond dramatically to the application of additional N, either via inorganic fertilizers or animal manures. Nitrate (NO_3^-)contamination of groundwater is of concern when excess N is leached beyond the rooting depth of plants. Nitrogen can also be lost to the atmosphere as NH_3 or NO_x. Currently, the cost of N is moderate on a monetary scale, but the cost has always been high in terms of energy.

Chicken litter is a relatively inexpensive source of nutrients that is often applied to pastures to supply N, P, and other nutrients. Soils in the Appalachian Piedmont are relatively poor in N and P. Therefore, plant production would likely respond positively to chicken litter application. However, excessive N and P can threaten water quality.

We hypothesized that with equivalent amounts of total N applied, the type of fertilization strategy (i.e., inorganic or organic) could affect the availability of N to forage and could therefore affect the quality and quantity of forage, leading to differences in soil C, N, and P accumulation rates. In addition, we wanted to ascertain the impact of forage harvest strategy (i.e., grazed or ungrazed) on the cycling of C, N, and P during the first five years of grass management following conversion from long-term cultivated cropland.

This presentation compiles a portion of the results from this long-term experiment on soil organic C (Franzluebbers et al., 2001), on total soil N (Franzluebbers and Stuedemann, 2001), and on Mehlich-I-extractable soil P (Franzluebbers et al., 2002).

2. Materials and methods

2.1. Site characteristics

A 15-ha upland field (33E 22' N, 83E 24' W) near Farmington, Georgia, USA had previously been conventionally cultivated with wheat (*Triticum aestivum* L.), soybean [*Glycine max* (L.) Merr.], sorghum [*Sorghum bicolor* (L.) Moench], and cotton (*Gossypium hirsutum* L.) for several decades prior to grassland establishment by sprigging of 'Coastal' bermudagrass in 1991. Mean annual temperature in the area is 16.5 EC, rainfall is 1250 mm, and potential evaporation is 1560 mm. Soils were mostly fine, kaolinitic, thermic Typic Kanhapludults with a small percentage of fine-loamy, micaceous, thermic Typic Hapludults and loamy, micaceous, thermic, shallow Ruptic-Ultic Dystrudepts. Soil texture of the Ap horizon was mostly sandy loam, with some areas of sandy clay loam, loamy sand, and loam. The average depth of the Ap horizon was 21 cm.

2.2. Experimental design

The experimental design was a randomized complete block with treatments in a split-plot arrangement in each of three blocks. Main plots were fertilization strategy (n=3) and split-plots were harvest strategy (n=4) for a total of 36 experimental units. Individual paddocks were 0.69±0.03 ha. Unharvested and hayed exclosures within each paddock were 100 m². Each paddock contained a 3 x 4 m shade, mineral feeder, and water trough placed in a line 15 m long near the top of the landscape.

Fertilization strategy consisted of - 20 g N $\cdot$ m^{-2} $\cdot$ yr^{-1} as (1) inorganic only (NH_4NO_3 broadcast in split applications in May and July), (2) crimson clover cover crop plus supplemental inorganic fertilizer (with half of the N assumed fixed by clover biomass and the other half as NH_4NO_3 broadcast in July), and (3) litter from broiler chickens (broadcast in split applications in May and July). Details of fertilizer applications each year are reported in Table 1. Phosphorus and potassium applications varied among treatments, because excess P and K were applied with broiler litter to meet N requirements, while diammonium phosphate and potash were applied based on soil testing recommendations. Crimson clover was direct drilled in clover treatments at - 1 g $\cdot$ m^{-2} in October each year. All paddocks were mowed in late April following soil sampling and residue allowed to decompose [i.e., clover biomass in clover plus inorganic treatment and winter annual weeds (primarily *Lolium multiflorum* L. and *Bromus catharticus* Vahl.) in other treatments].

Harvest strategy mimicked a gradient in forage utilization consisting of (1) unharvested (biomass cut and left in place at the end of growing season), (2) low

Table 1. Characteristics and rates of fertilizers applied (g $\cdot$ m^{-2} $\cdot$ yr^{-1}).

Variable	1994	1995	1996	1997	1998	5-yr mean
			Inorganic only			
N	21.1	20.2	25.0	23.8	22.4	22.5
P	0	2.4	2.4	2.4	0.7	1.6
K	0	4.7	9.3	9.3	2.8	5.2
			Clover + inorganic[a]			
N	21.1	10.1	13.2	12.0	11.1	13.5
P	0	3.3	4.9	2.4	0.7	2.3
K	0	6.2	9.3	9.3	2.8	5.5
			Broiler litter			
Dry mass	522	650	519	502	504	539
Moisture (g $\cdot$ g^{-1})	0.25	0.30	0.27	0.19	0.28	0.26
C	183	205	169	193	166	183
S	2.0	2.6	2.6	2.3	1.7	2.2
N	19.5	21.6	16.4	22.3	17.2	19.4
P	11.8	14.1	11.2	6.9	17.8	12.4
K	16.9	24.3	16.8	11.5	14.0	16.7

[a] An additional 11 g N $\cdot$ m^{-2} $\cdot$ yr^{-1} was assumed to be supplied in clover cover crop biomass through biological N fixation from 1995 to 1998.

grazing pressure (put-and-take system to maintain a target of - 300 g · m^{-2} of available forage), (3) high grazing pressure (put-and-take system to maintain a target of - 150 g · m^{-2} of available forage), and (4) hayed monthly to remove above-ground biomass at 4-cm height. Yearling Angus steers (*Bos taurus*) grazed paddocks during a 140-d period from mid May until early October each year. No grazing occurred in the winter. Animals were weighed, available forage determined, and paddocks restocked on a monthly basis.

2.3. Sampling and analyses

Soil and surface residue were sampled in April prior to grazing during most years. Sampling locations within grazed paddocks were within a 3-m radius of points on a 30-m grid. Due to the nonuniform dimensions of paddocks, sampling sites within a paddock varied from four to nine, averaging 7±1. Two sampling locations were fixed within each hayed and unharvested exclosure. Surface residue was collected from a 0.25-m^2 area at each sampling point following removal of vegetation at a height of - 4 cm. Surface residue, including plant stubble, was cut to the mineral surface with battery-powered hand shears, bagged, and dried at 70 EC for several days. During 1994 and 1995, soil was sampled at depths of 0 to 2, 2 to 4, and 4 to 6 cm from the composite of two 8.5-cm-diam cores within each sampling location. From spring 1996 until the spring of 1998, soil was sampled to the same depths from the composite of nine 4.1-cm-diam cores within each sampling location. Soil was air-dried and ground to <2 mm in a mechanical grinder in 1994 and 1995. Soil was oven-dried (55 EC, 72 hr) and gently crushed to pass a 4.75-mm screen in all other years.

Beginning in February 1999, sampling strategy was changed to (1) collect surface residue and soil only once per year, (2) more directly address the zonal changes in pastures in response to animal behavior near shade and water sources, and (3) collect soil to deeper depths. Surface residue was collected from a composite of eight 0.04-m^2 areas randomly selected within each of three zones within paddocks (i.e., 0 to 30, 30 to 70, and 70 to 120 m distances from livestock shades) and within each exclosure. Surface residue was processed as described previously. A single 4.1-cm-diam soil core was collected from each of the eight residue sampling sites and composited. Soil was collected at depths of 0 to 3, 3 to 6, 6 to 12, and 12 to 20 cm, oven-dried (55 EC, 72 hr), and gently crushed to pass a 4.75-mm screen.

Soil bulk density was calculated from the oven-dried soil weight (55 EC) and pooled-core volume (2.26-8.45 x 10^{-4} m^3, depending upon depth of sampling). Surface residue was ground to <1 mm and a 20- to 30-g soil subsample from each composite sample was ground to a fine powder in a ball mill for 3 min prior to analysis of total C and N with dry combustion at 1350 EC (Leco CNS-2000, St. Joseph, MI).[1] It was assumed that total C was equivalent to organic C because soil pH was near 6.

Mehlich-I extractable soil P (Nelson et al., 1953) was determined (10 g soil shaken with 40 mL of 0.05 *M* HCl + 0.0125 *M* H$_2$SO$_4$ for 15 minutes and filtered) with a

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[1]Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

molybdate autoanalyzer technique (Olsen and Sommers, 1982). Total soil P of the 0- to 3- and 3- to 6-cm depths was determined with inductively coupled plasma spectroscopy (ICPS) following perchloric acid digestion (Olsen and Sommers, 1982) for soils collected in February 1999, for which three subsampling units (i.e., 20 g from each of the samples representing the 0 to 30, 30 to 70, and 70 to 120 m distances from shade) within each grazed paddock were composited.

Data from multiple samples within an experimental unit were averaged and not considered as a source of variation in the analysis of variance (SAS Institute, 1990). Within-depth, across-depth, within-year, and across-year analyses were conducted according to the split-plot design with three blocks. Across-depth analyses considered the bulk density of soil in calculating standing stock values of soil organic C and total N and P. Across-year analyses considered years as repeated measures. Effects were considered significant at P#0.1.

3. Results and discussion

3.1. Fertilization strategy

Fertilization strategy of bermudagrass had little effect on the rate of accumulation of soil organic C and total soil N, but had a major impact on the accumulation of Mehlich-I-extractable soil P (Fig. 1). Soil organic C at a depth of 0-6 cm accumulated at an average rate of 94 g · m^{-2} · yr^{-1} across fertilization regimes. Interestingly, the additional input of C with broiler litter fertilization did not translate into significantly greater accumulation of soil organic C. This may be due to the relatively warm and moist climatic conditions in the region, which favored rapid and near complete decomposition of the organic amendment. From a study in northern Alabama USA, retention of C in surface soil from broiler litter was estimated at - 8% of that applied (Kingery et al., 1994).

Total soil N accumulated at an average rate of 10.3 g · m^{-2} · yr^{-1} across fertilization regimes (Fig. 1). The lack of difference among fertilization regimes in the rate of total soil N accumulation suggests that N application in each system may have led to similar plant production and transformation of plant decomposition products into soil organic matter. It is also possible that there may have been some shifts in the balance
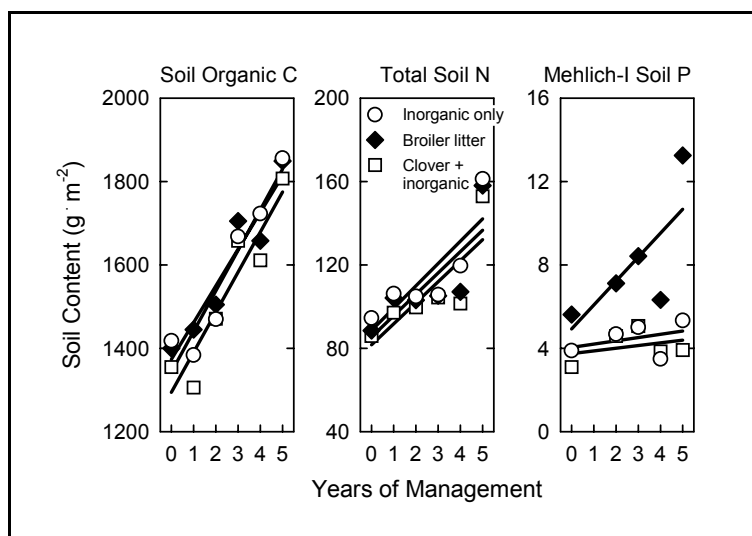

Figure 1. Changes in the contents of soil organic C, total soil N, and Mehlich-I extractable soil P with time at a depth of 0-6 cm as affected by fertilization strategy of 'Coastal' bermudagrass.

between quality and quantity of plant components in response to fertilization strategies, but these intermediate steps were not determined in this study.

Mehlich-I-extractable soil P accumulated at a rate of $1.15 \, g \cdot m^{-2} \cdot yr^{-1}$ with broiler litter fertilization and at an average rate of $0.14 \, g \cdot m^{-2} \cdot yr^{-1}$ with inorganic only and clover + inorganic fertilization (Fig. 1). Phosphorus inputs averaged 1.6, 2.3, and $12.4 \, g \cdot m^{-2} \cdot yr^{-1}$,
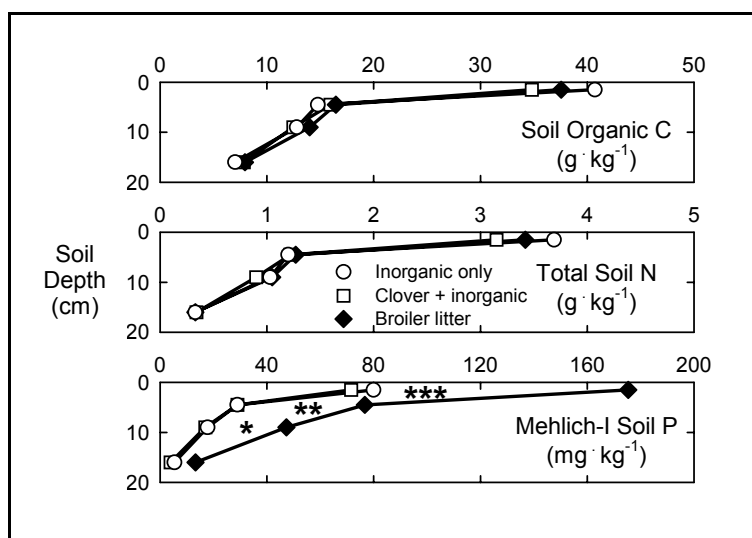

Figure 2. Depth distribution of soil organic C, total soil N, and Mehlich-I-extractable soil P at the end of 5 years of fertilization of 'Coastal' bermudagrass under different strategies. ***, **, and * indicate significance at P#0.001, P#0.01, and P#0.1, respectively.

suggesting that Mehlich-I-extractable soil P accumulated at a rate of 10% of applied P with inorganic only fertilization, 6% of applied P with clover + inorganic fertilization, and 9% of applied P with broiler litter fertilization. Adsorption of P onto soil colloids was likely a major pathway that limited the accumulation of Mehlich-I-extractable soil P in these systems. Ultisols in southeastern USA, which have copious quantities of particulate and colloidal Fe- and Al-oxides, have a great affinity to adsorb P on these reactive surfaces (Anderson et al., 1996).

Depth distribution of soil organic C and total soil N were not significantly affected by fertilization strategy (Fig. 2). Both soil organic C and total soil N were very high at the soil surface at the end of five years of management and decreased sharply with depth. If we were to broadly assume that the 6-20-cm depth were considered a starting point of soil organic C and total soil N prior to establishment of bermudagrass in 1991 (since soil was tilled prior to this time), then accumulation of soil organic C and total soil N to a depth of 20 cm during the ensuing eight years would have been 118 and 12.9 $g \cdot m^{-2} \cdot yr^{-1}$, respectively. These estimates would be only 25% greater than those obtained during the 5-year experimental period, suggesting that most of the organic matter accumulation does indeed occur within the surface 6 cm in this warm–moist climate. The source of C would have been partially decomposed plant material derived from above- and below-ground components before and during the experimental period. The source of N would have been fertilizer sources during the experimental period, as well as redistribution of N from lower depths to the surface following plant uptake and subsequent decomposition.

Mehlich-I-extractable soil P was significantly greater with broiler litter fertilization at depths of 0-3, 3-6, and 6-12 cm than with inorganic only or clover + inorganic fertilization (Fig. 2). Vertical movement of surface-applied P from broiler litter was limited to the surface 12 cm. Adsorption of P to soil must have been a significant process that occurred under these pastures. The difference in P application rate between

broiler litter and other fertilization strategies was equivalent to 62 mg · kg^{-1} · yr^{-1} to a depth of 12 cm. At the end of five years, the difference in Mehlich-I-extractable soil P between broiler litter and other fertilization strategies was equivalent to 48 mg · kg^{-1} to a depth of 12 cm, suggesting that only 15% of applied P led to an increase in the extractable soil P pool.

3.2. Harvest strategy

The effects of harvest strategy with time were relatively consistent whether the response variable was soil organic C, total soil N, or Mehlich-I-extractable soil P (Fig. 3). The dominant harvest strategy effect was between grazed and ungrazed management systems. Soil organic C at a depth of 0-6 cm accumulated at a rate of 140 g · m^{-2} · yr^{-1} under both grazing pressures, at a rate of 65 g · m^{-2} · yr^{-1} under unharvested
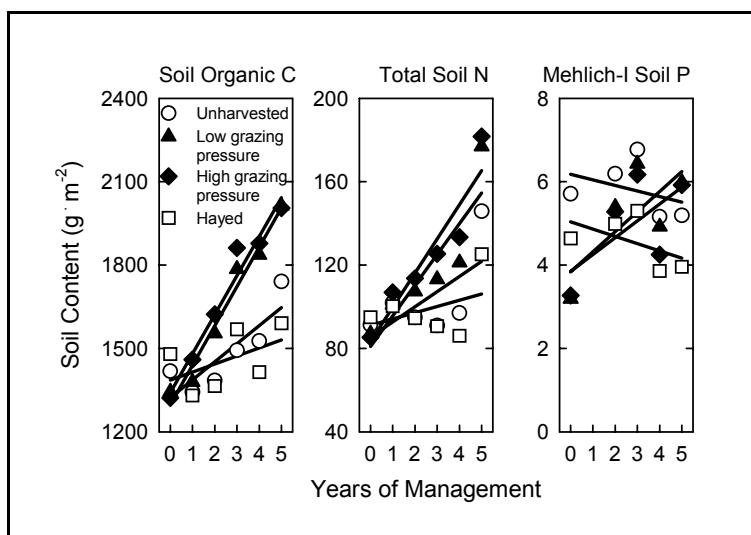

Figure 3. Changes in the contents of soil organic C, total soil N, and Mehlich-I extractable soil P with time at a depth of 0-6 cm as affected by harvest strategy of 'Coastal' bermudagrass.

management, and at a rate of 29 g · m^{-2} · yr^{-1} under hayed management. Cattle consumed forage and deposited feces back to the soil where this organic matter quickly became a part of the soil organic pool.

Total soil N at a depth of 0-6 cm accumulated at a rate of 16.4 g · m^{-2} · yr^{-1} under high grazing pressure, at a rate of 14.7 g · m^{-2} · yr^{-1} under low grazing pressure, at a rate of 7.3 g · m^{-2} · yr^{-1} under unharvested management, and at a rate of 3.0 g · m^{-2} · yr^{-1} under hayed management (Fig. 3). With an average rate of N applied of 21.8 g · m^{-2} · yr^{-1}, sequestration of N into soil organic matter of the surface 6 cm was equivalent to 75% of total N applied under high grazing pressure, 67% of total N applied under low grazing pressure, 33% of total N applied under unharvested management, and 14% of total N applied under hayed management. This suggests that fertilizer applications to pastures during early years contributes to the long-term fertility of soil, especially near the surface where it can be readily utilized by subsequent plant roots.

Mehlich-I-extractable soil P at a depth of 0-6 cm accumulated at a rate of 0.5 g · m^{-2} · yr^{-1} under high grazing pressure and at a rate of 0.4 g · m^{-2} · yr^{-1} under low grazing pressure (Fig. 3). In contrast, Mehlich-I-extractable soil P tended to decline with time under unharvested (-0.1 g · m^{-2} · yr^{-1}) and hayed (-0.2 g · m^{-2} · yr^{-1}) management. The removal of P with hay would have been expected to create a heavy demand on the labile pool of P. The relatively stable level of extractable soil P under unharvested management was mostly due to the fact that a few of the unharvested exclosures were

located on areas with relatively high initial extractable soil P, which probably limited the release of P into the labile pool because of the reduced concentration gradient between total and labile pools. Cattle grazing returns most of the P consumed in forage back to the soil as feces, which led to an increase in the extractable soil P pool with recurring fertilization.
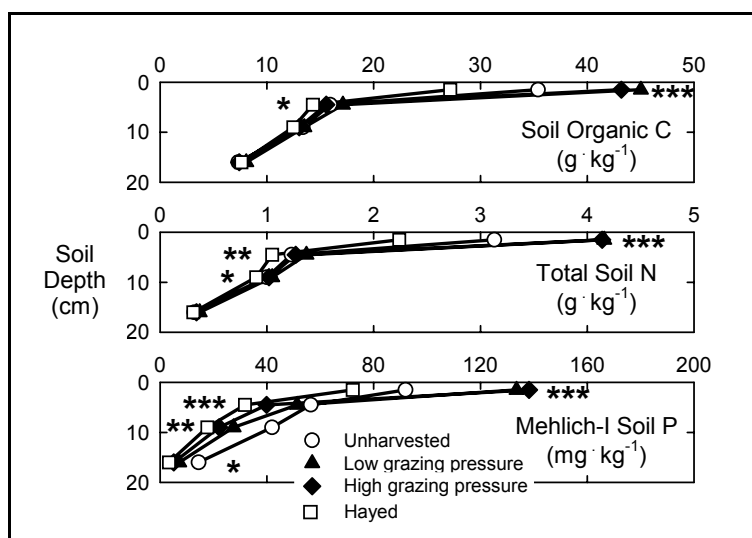

Figure 4. Depth distribution of soil organic C, total soil N, and Mehlich-I-extractable soil P at the end of 5 years of different harvest strategies of 'Coastal' bermudagrass. ***, **, and * indicate significance at P#0.001, P#0.01, and P#0.1, respectively.

Depth distribution of soil organic C and total soil N were affected by harvest strategy (Fig. 4). For both elements, concentrations were greatest at the soil surface and declined dramatically with depth. Concentrations of soil organic C and total soil N were 22-33% greater under grazed management than under unharvested management and 59-86% greater than under hayed management at a depth of 0-3 cm. At a depth of 3-6 cm, concentrations of soil organic C and total soil N under grazed management were not different to 11% greater than under unharvested management and 9-30% greater than under hayed management. Few significant differences among harvest strategies occurred below 6 cm.

Mehlich-I-extractable soil P under grazed management at a depth of 0-3 cm was 45-50% greater than under unharvested management and 85-92% greater than under hayed management (Fig. 4). At lower depths, Mehlich-I-extractable soil P under grazed management was equivalent or lower than under unharvested management, but 25-115% greater than under hayed management.

3.3. Spatial distribution within pasture

Distribution of nutrients within grazed pastures was affected by proximity to shade and water sources (Fig. 5). Contents of soil organic C, total soil N, and Mehlich-I-extractable soil P in the surface 6 cm were greater in the 0-30-m zone around shade and water than farther away with broiler litter and clover + inorganic fertilization, but not with inorganic only fertilization. It is not clear why the spatial distribution of nutrients under inorganic only fertilization was different than under other fertilization strategies. Cattle spend a disproportionately greater amount of time near shade and water sources than other areas of a pasture, because of the need for water, minerals, and seeking relief from the sun. Consequently, more feces and urine are deposited near shade and water sources than other areas of the pasture, resulting in accumulation of nutrients near shade and water sources.

4. Summary and conclusions

Fertilization strategy (when based on an equivalent N application rate of 22 g · m^{-2} · yr^{-1}) during the first five years of bermudagrass management had little affect on the accumulation rate and depth distribution of soil organic C and total soil N. However, fertilization strategy did have a large effect on the accumulation rate and depth distribution of Mehlich-I-extractable soil P.
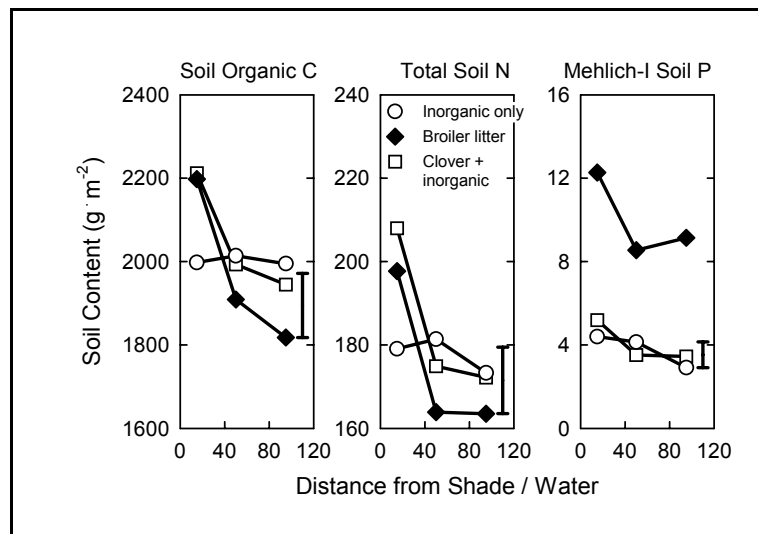

Figure 5. Spatial distribution within pastures at the end of 5 years in the contents of soil organic C, total soil N, and Mehlich-I extractable soil P at a depth of 0-6 cm as affected by fertilization strategy of 'Coastal' bermudagrass. Error bar indicates LSD at P=0.1.

Fertilization with broiler litter provided a relatively modest input of C (183 g · m^{-2} · yr^{-1}), equivalent input of N, and several-fold greater level of P input (12.4 vs. - 2.0 g · m^{-2} · yr^{-1}) than with other fertilization strategies (i.e., inorganic only and clover + inorganic). Since soils in the southeastern USA have a great affinity to adsorb P and, therefore, respond agronomically and economically to fertilization with P, broiler litter can be considered an excellent fertilizer to replenish soil fertility. Caution must be made of the high P concentration relative to N concentration, which could cause water quality problems if excessive application were to occur and water runoff control strategies were not implemented.

Harvest strategy (i.e., unharvested, low and high cattle grazing pressure, and haying) significantly affected accumulation rate and depth distribution of soil organic C, total soil N, and Mehlich-I-extractable soil P. Grazing led to accumulation rates of soil organic C and total soil N 2-5 times those of unharvested or hayed management. Grazing of pastures significantly increased the Mehlich-I-extractable soil P with time, while ungrazed management led to unchanged or decreasing levels with time. Most of the changes in nutrients due to harvest management occurred within the surface 6 cm.

Spatial distribution of nutrients in grazed pastures was controlled by proximity to shade and water sources, resulting in a disproportionate amount of feces deposited in these areas.

Acknowledgements

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